

AD-A277 743



2

ARMY RESEARCH LABORATORY

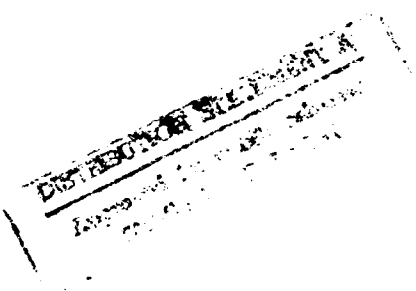


Diffusion and Sorption of 1,4-Dioxane Into Polychloroprene

Geralda Severe

ARL-TR-338

February 1994



DTIC
ELECTE
APR 05 1994
S B D

DTIC QUALITY INSPECTED 3

for public release; distribution unlimited.

2578 94-10188



94 4 4 110

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.

Accession For	
DTIC GRA&I	<input checked="checked" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution	
Availability Codes	
Dist	Avail and/or Special
A	

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
<small>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.</small>				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE February 1994		3. REPORT TYPE AND DATES COVERED Final Report
4. TITLE AND SUBTITLE Diffusion and Sorption of 1,4-Dioxane into Polychloroprene			5. FUNDING NUMBERS	
6. AUTHOR(S) Gerald Severe				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory Watertown, MA 02172-0061 ATTN: AMSRL-MA-PB			8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TR-338	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory 2800 Powder Mill Road Adelphi, MD 20783-1197			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) Influence of the presence of plasticizer on the transport properties for the polychloroprene/1,4-dioxane (Neoprene/1,4-dioxane) system has been investigated. The sorption rate curves for the extracted and the unextracted (as received) Neoprene demonstrated some characteristics of Fickian behavior. The sorption isotherms obtained from the weight uptake did not coincide for repeated runs of the extracted sample; they were below the isotherm of the unextracted sample. However, both types of samples (extracted and unextracted Neoprene) showed diffusion coefficients that increase with concentration. The difference between the diffusion coefficients for the extracted and unextracted Neoprene was not significant; the extraction primarily affected the solubility.				
14. SUBJECT TERMS Neoprene, 1,4-Dioxane, Vapor, Sorption, Sorption isotherm, Diffusion coefficient			15. NUMBER OF PAGES 24	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL	

Contents

	Page
Introduction	1
Experimental	1
Liquid Immersion	1
Vapor Sorption	2
Results and Discussion	
Sorption Curve Analysis	6
Diffusion Coefficients	9
Sorption Isotherms	13
Conclusion	14
Acknowledgment	15
References	15

Figures

1. Sorption curves for Neoprene (unextracted) at $a = 0.8$	3
2. Sorption curves for Neoprene (unextracted) at $a = 0.9$	3
3. Sorption curves for Neoprene (extracted) at $a = 0.9$ (second run)	4
4. Sorption curves for Neoprene (unextracted) at $a = 0.8$	4
5. Sorption curves for Neoprene (unextracted) at $a = 0.9$	5
6. Sorption curves for Neoprene (extracted) at $a = 0.9$ (second run)	5
7. Sorption curves for the unextracted Neoprene at different activity	6
8. Sorption curves for the unextracted Neoprene at different activity (first run)	7
9. Sorption curves for the unextracted Neoprene at different activities (second run)	7
10. Comparison of the two sets of data obtained at different activities for the same extracted Neoprene sample	8
11. Investigation of the influence of plasticizer on the sorption curves at different activities	9
12. Investigation of the influence of plasticizer on the diffusion coefficient.	11
13. Investigation of the influence of plasticizer on the mutual and self-diffusion coefficient	12

14. Investigation of the influence of plasticizer on the sorption isotherm.	13
15. Comparison of Flory-Rhener isotherm with the experimental data for the unextracted sample	14

Tables

1. Smithers No. L0831 (Neoprene)	2
2. Unextracted Neoprene sample	10
3. Extracted Neoprene sample (first run)	10
4. Extracted Neoprene sample (second run)	11

Introduction

Insufficient agreement between the droplet permeation model (1) and the experimental data for the permeation of di-isopropylmethylphosphonate (DIMP) in Neoprene (2) prompted inquiry about the diffusion behavior for the mentioned polymer/solvent system. However, there is an absence of information in the literature to verify the assumption that the diffusion coefficient of DIMP in the DIMP/Neoprene system was independent of concentration. As such, the difficulty justifying the discrepancy between theory and experiment prompted the experimental study of the DIMP/Neoprene system.

Among the methods available to obtain the diffusion coefficient, vapor sorption is the best for investigating concentration dependence. Unfortunately, the vapor sorption apparatus at the U.S. Army Research Laboratory (ARL) in Watertown, MA was not able to provide the ballast volume needed to maintain constant vapor pressure of DIMP during the sorption or desorption runs because of the extremely low vapor pressure of DIMP. To obtain the necessary information without going through the redesigning of the apparatus, the same study was done with 1,4-dioxane which has a high vapor pressure than DIMP. The magnitudes in the weight uptake by the extracted Neoprene with both solvents were similar enough to make it a plausible substitution.

Experimental

Experiments (immersion and vapor sorption) were carried on Neoprene samples with a nominal thickness of 0.0305 and 0.0356 cm (12 and 14 mils) that were compounded by Smithers Scientific Services of Akron, OH. To extract the plasticizer (Diester of Triethylene Glycol), which constituted about 9% weight of the total amount of ingredients present (see Table 1) (2), a sample of Neoprene was immersed in toluene that was constantly stirred for one week. The Neoprene was then dried in a vacuum oven at 50°C until it reached an equilibrium weight. An average weight loss of 12.86% was recorded at the end of the extraction process. Two specimens were made from this extracted neoprene; one was used for the vapor sorption studies and the other to obtain the equilibrium weight gain by immersing it into 1,4-dioxane at 30°C.

Liquid Immersion

The weight changes of Neoprene during liquid immersion experiments were measured by microbalance after removing the sample from the solvent and blotting it dry as quickly as possible. The weight changes were recorded on the second, tenth, and the thirty-fourth day for the extracted sample for an overall period of thirty-four days. The unextracted (as received) sample was weighed after thirteen, twenty-six, and forty-eight days. The duration of the immersion experiments was forty-eight days for the unextracted (as received) sample. At the end, the equilibrium weight gain for the unextracted sample was 79% while the extracted sample was 69%.

DTIC QUALITY INSPECTED 3

Table 1. Smithers No. L0831 (Neoprene)

Ingredient	PHR	Grams
Neoprene W	100	760
Scorchguard O	4	30.4
Stearic Acid	0.5	3.8
Wingstay 100 AZ	2	15.2
Age Rite Stalite S	1	7.6
N-774 Carbon Black	65	494.4
Van Wax H	1	7.6
Plasticizer	18	136.8
Darvan ME	1	7.6
Polyethylene AC617	1	7.6
Zinc Oxide	5	38.0
Ackrochem ETU-22 PM	0.67	5.1
Methyl Tuads	0.5	3.8
Totals	199.67	1517.5

Vapor Sorption

The weight uptake of 1,4-dioxane into the unextracted (as received) and extracted neoprene was measured using the incremental vapor sorption method. The sample was suspended from a helical quartz spring in a temperature controlled glass vacuum apparatus. The solvent uptake was measured as a function of time by measuring the extension of the spring with a cathetometer. The spring extension was followed until there was no further change in its length. This procedure was repeated successfully to an activity of 0.7 (a = partial pressure/saturation pressure). At higher activities (a = 0.8 and 0.9) the experiments were interrupted because it was difficult for the spring to reach an equilibrium deflection (see Figures 1, 2, and 3). For the purpose of data analysis, the equilibrium deflection in those cases was taken as the height reached by the suspended sample after 20 to 31 minutes from the start of the experiment before occurrence of the fluctuation (see Figures 4, 5, and 6). Once the sorption process was completed it was immediately followed by a desorption process over the same range of pressure. As during the sorption process, the displacement and the pressure were measured as a function of time until an equilibrium length of the spring was achieved. Again, the changes in length were converted into weight loss. The results for the desorption process are not reported in this paper.

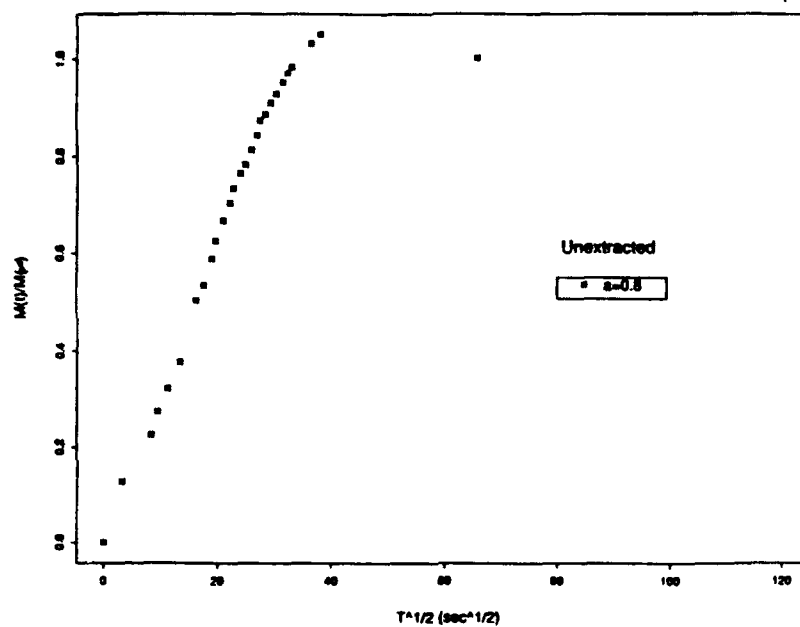


Figure 1. Sorption curves for Neoprene (unextracted) at $a = 0.8$.

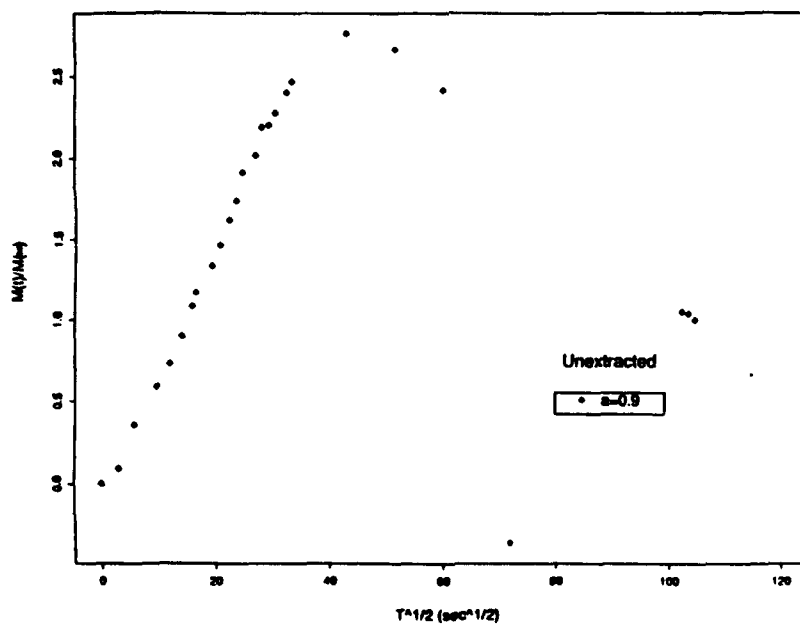


Figure 2. Sorption curves for Neoprene (unextracted) at $a = 0.9$.

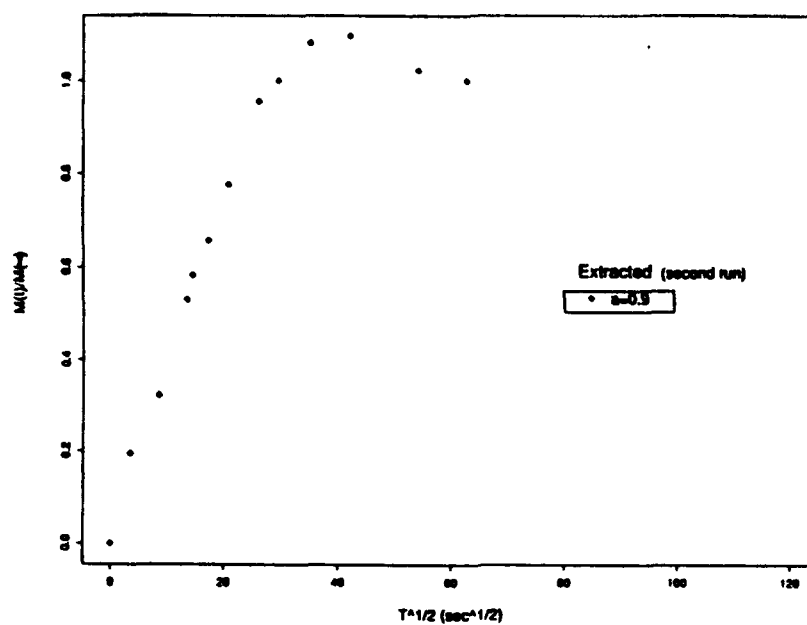


Figure 3. Sorption curves for Neoprene (extracted) at $a = 0.9$ (second run).

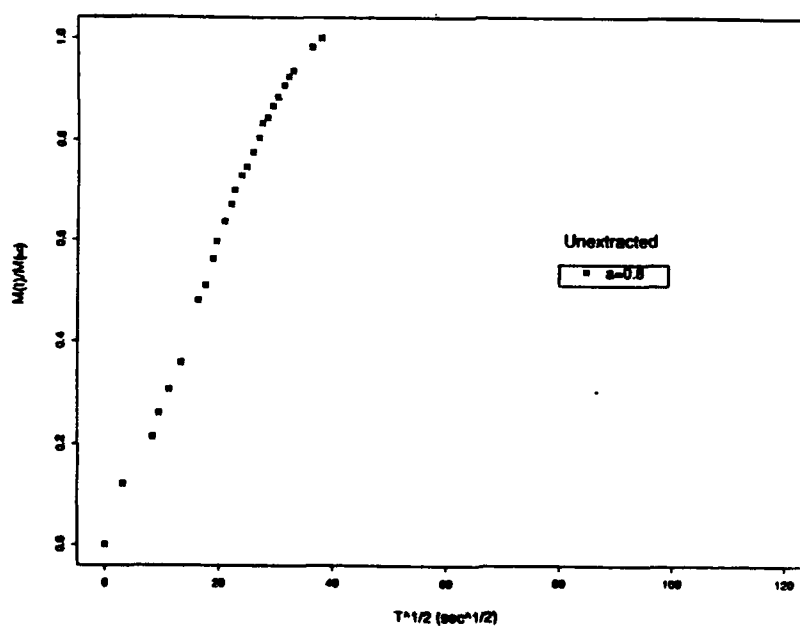


Figure 4. Sorption curves for Neoprene (unextracted) at $a = 0.8$.

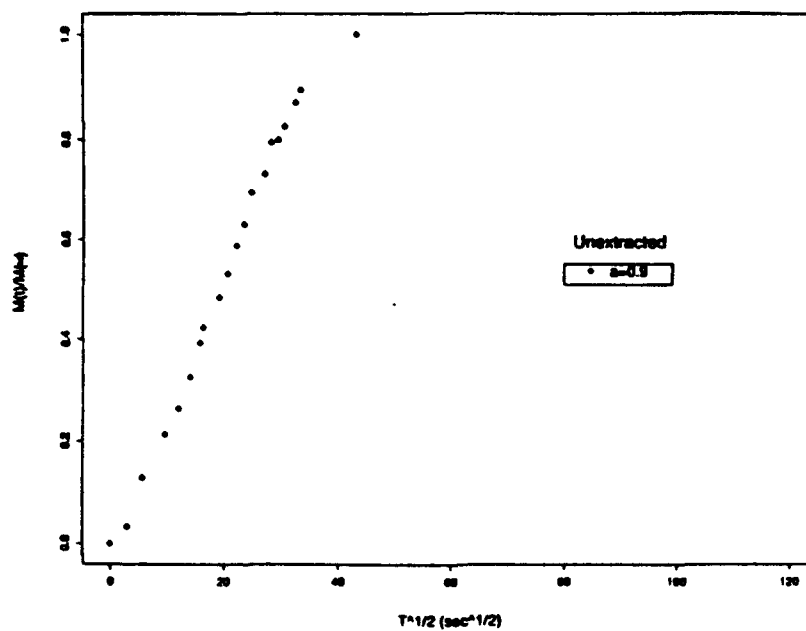


Figure 5. Sorption curves for Neoprene (unextracted) at $a = 0.9$.

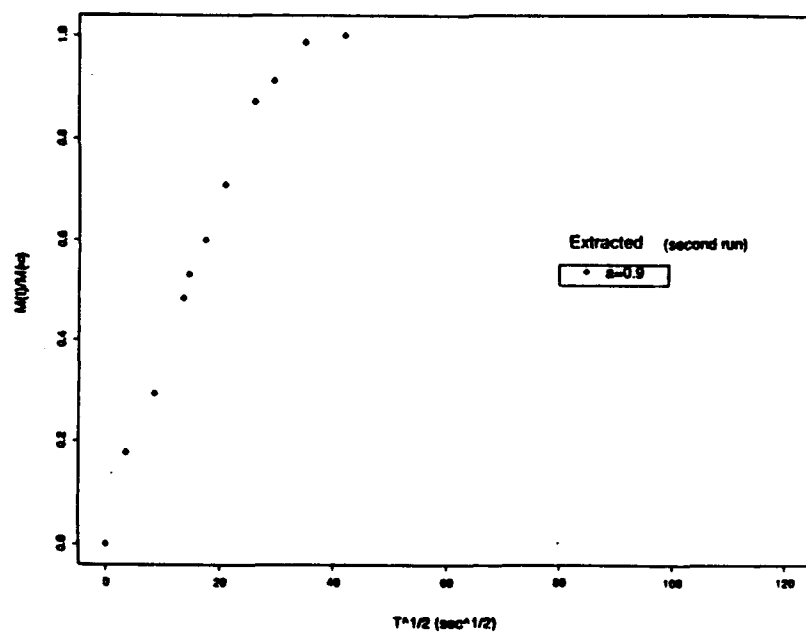


Figure 6. Sorption curves for Neoprene (extracted) at $a = 0.9$ (second run).

Results and Discussion

Sorption Curve Analysis

Data obtained from the sorption experiments were plotted as $M(t)/M(\infty)$ (fractional weight uptake) versus square root of time (see Figures 7, 8, and 9), also known as sorption curves, where $M(t)$ represents the weight absorbed by the sample at time t , and $M(\infty)$ represents the equilibrium vapor absorbed. The sorption curves were analyzed to determine whether they exhibited Fickian behavior, which would be indicated when the sorption curves are linear in the initial stage (up to 60% or more) and concave to the time axis at higher sorption amounts. Furthermore, the results for different thickness must overlap when plotted as $M(t)/M(\infty)$ versus $t^{1/2}/L$ (3).

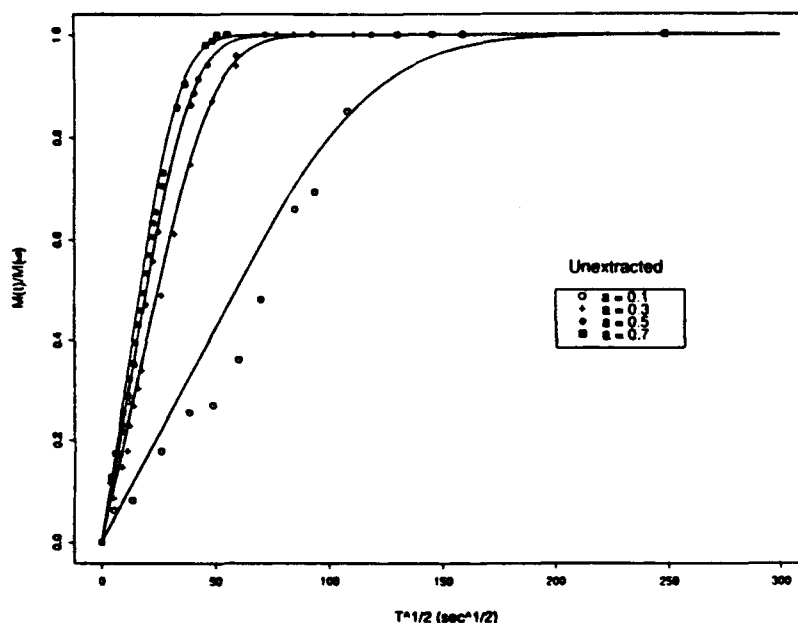


Figure 7. Sorption curves for the unextracted Neoprene at different activity.

The vapor sorption curves for the extracted and the unextracted Neoprene samples with 1,4-dioxane had shown the first two characteristics of a Fickian behavior. They were linear in the early stage and were concave to the time axis beyond the linear portions (see Figures 7, 8, and 9). Since the experiments were not performed at different thicknesses, a conclusion on Fickian behavior cannot be made. Comparison of the sorption curves for the unextracted (as received) sample with the sorption curves obtained by Khinnavar and Aminabhavi (4) had shown a different behavior. Their reported results for the immersion tests of 1,4-dioxane at 25°C demonstrate an initial sigmoidal shape which could result from the fact that their test samples were thicker (thickness range of 0.190 and 0.245 cm). The response of the polymer to stresses induced by swelling due to the sorption of solvent may be slower for a thicker material than for a thinner material.

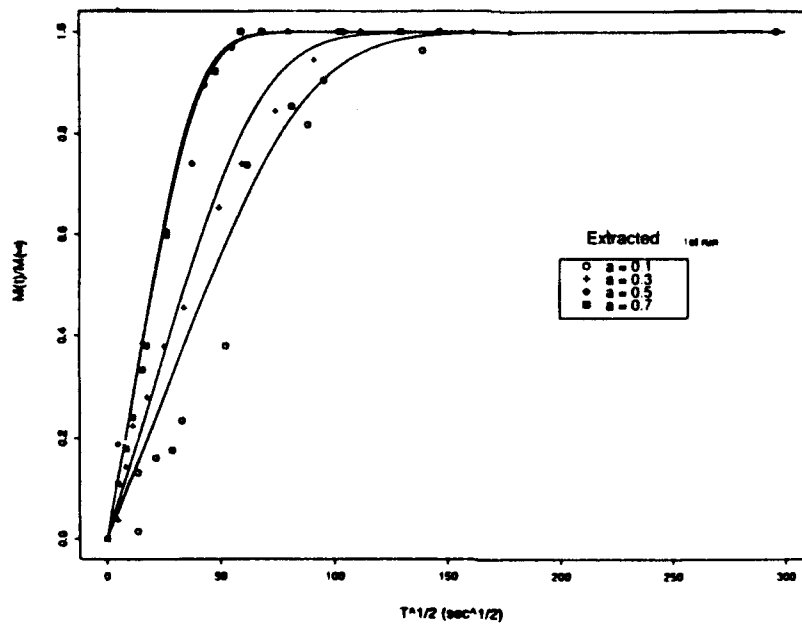


Figure 8. Sorption curves for the unextracted Neoprene at different activity (first run).

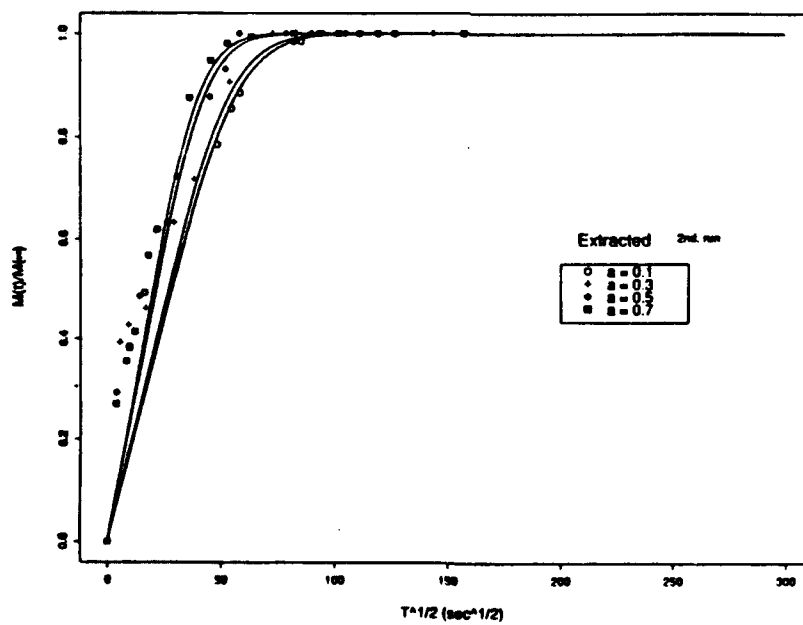


Figure 9. Sorption curves for the unextracted Neoprene at different activities (second run).

To ascertain the results obtained for the extracted analysis, repeated sorption experiments were done with the same sample. Repeated sorption cycling did not affect the sorption behavior. However, the rate of weight uptake was not identical for the different runs. The rate was slower for the first exposure and faster with each new cycle (see Figure 10). This behavior was not anticipated. Both Neoprene extracted and as received had also shown that the rate uptake increases with activity which is an indication that the diffusion constant is a function of concentration.

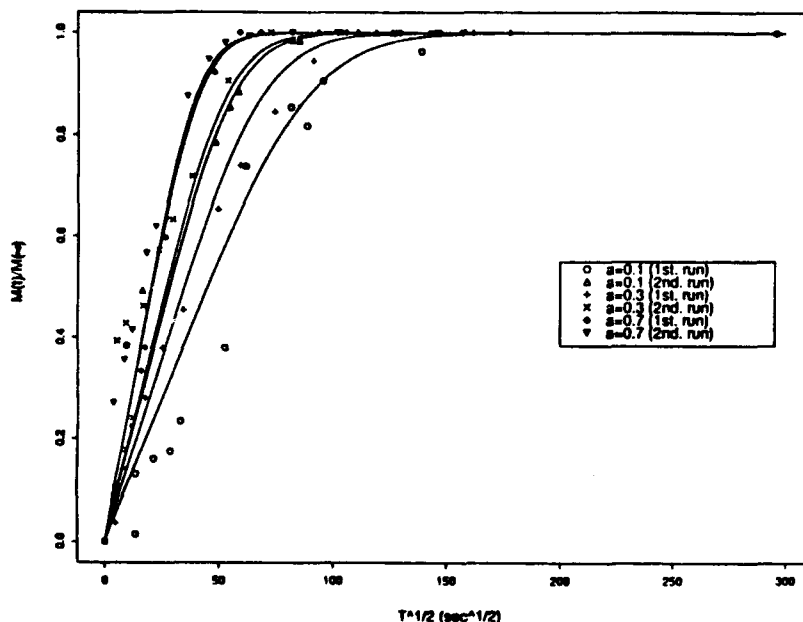


Figure 10. Comparison of the two sets of data obtained at different activities for the same extracted Neoprene sample.

Comparison of the sorption rate uptake for the extracted with the unextracted (as received) samples demonstrated mixed behavior. At lower activity; i.e., at $a = 0.1$ and 0.2 , the uptake for the extracted sample was faster and at $a = 0.3$ and higher the opposite occurred (see Figure 11). The expectations were that the presence of plasticizer would facilitate the sorption thereby speed up the uptake. No plausible explanation had been reached on this particular behavior.

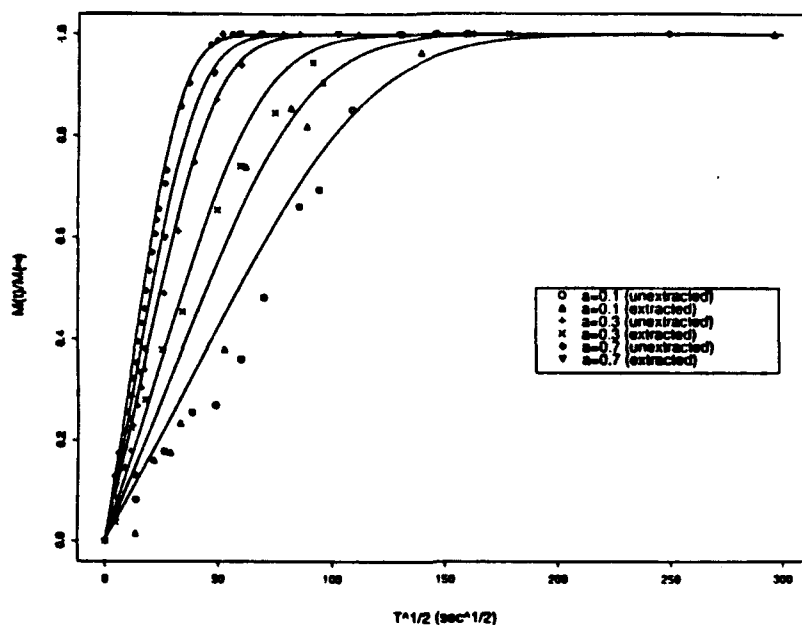


Figure 11. Investigation of the influence of plasticizer on the sorption curves at different activities.

Diffusion Coefficients

Although the diffusion coefficient (D) during each sorption step was considered to be constant, taken together it was a function of concentration. To obtain a numerical value for the diffusion coefficient, since the sorption curves were linear up to 60% of concentration, the half-time method was used to obtain a value for the diffusion coefficient to substitute into:

$$\frac{M(t)}{M(\infty)} = 1 - \frac{8}{\pi^2} \sum_{m=0}^{\infty} \frac{1}{(2m+1)^2} \exp\left(\frac{-Dt(2m+1)^2\pi^2}{l^2}\right) \quad (1)$$

where $M(t)$ and $M(\infty)$ were as defined earlier, D , the diffusion coefficient and l , the thickness of the dry sample (5). The fractional weight of uptake acquired from Equation 1 was plotted versus square root of time (see Figures 9, 10, and 11). The solid lines on the sorption curves, as shown in Figures 9, 10, and 11, represent the results of the above equation. However, the diffusion coefficients obtained from the above equation were an approximation of a mean diffusion coefficient in the sorption interval.

Duda, et al. (6), had shown that the actual $D(c)$ can be set equal to the mean diffusion coefficient ($\bar{D}(c)$) with minor error at a prescribed concentration interval, with \bar{D} depending upon whether D increased or decreased with concentration. In a sorption experiment, if D was an increasing function of concentration, k in Equation 2 was set to 0.7 (0.56 otherwise). As seen from Tables 2 through 4, the diffusion coefficient increased with concentration; therefore, $k = 0.7$ was used to calculate the prescribed concentration (c) which was sometimes referred to as the adjusted concentration:

$$c = c_i + k(c_f - c_i). \quad (2)$$

Table 2. Unextracted Neoprene sample

Activity coefficient	Concentration (mg solvent/mg polymer) x 100	Adjusted concentration (defined in Equation 2)	Diffusion coefficient $D \times 10^8$ (cm ² /sec)
0.1	1.34	0.94	1.00
0.2	2.21	1.95	3.47
0.3	3.91	3.40	8.92
0.4	5.91	5.31	11.7
0.5	8.46	7.70	15.5
0.6	11.69	10.72	20.8
0.7	16.18	14.83	19.2
0.8	27.32	23.98	25.0
0.9	34.96	32.67	18.3

Table 3. Extracted Neoprene sample (first run)

Activity coefficient	Concentration (mg solvent/mg polymer) x 100	Adjusted concentration (defined in Equation 2)	Diffusion coefficient $D \times 10^8$ (cm ² /sec)
0.1	1.125	0.788	2.65
0.2	1.73	1.55	4.25
0.3	3.05	2.65	5.05
0.4	4.54	4.09	5.87
0.5	5.33	5.09	13.2
0.6	6.30	6.01	10.8
0.7	7.36	7.04	12.5
0.8	8.37	8.067	33.3
0.9	11.53	10.582	16.5

Table 4. Extracted Neoprene sample (second run)

Activity coefficient	Concentration (mg solvent/mg polymer) x 100	Adjusted concentration (defined in Equation 2)	Diffusion coefficient $D \times 10^8$ (cm ² /sec)
0.1	0.821	0.57	6.67
0.2	1.27	1.14	7.17
0.3	1.99	1.77	7.42
0.4	2.75	2.52	10.5
0.5	3.57	3.32	11.7
0.6	4.65	4.33	11.7
0.7	5.65	5.35	13.3
0.8	10.28	9.41	18.3
0.9	11.73	11.30	26.7

The plot of D versus concentration for the unextracted sample (see Figure 12) increased rapidly at low concentration then tended to level off. Extrapolation for the zero concentration diffusion coefficient was found to be about $4.0\text{E-}9$ cm²/sec. This value is lower than the diffusion coefficient at $c = 0$ (D_0) for natural rubber in toluene which was $7.8\text{E-}8$ cm²/sec (7) and higher than the diffusion coefficient for butyl rubber in toluene ($1.2\text{E-}9$ cm²/sec) (8). The values obtained for the diffusion coefficient in the analysis of the extracted sample display a rapid increase of diffusion coefficient as activity increases. However, these data seem to have larger errors than the results for the unextracted sample. The values obtained for the two sets of data for the extracted Neoprene were difficult to interpret; they did not overlap with each other nor did they show a clear trend (see Figure 12). Literature data for comparison purposes have not been found.

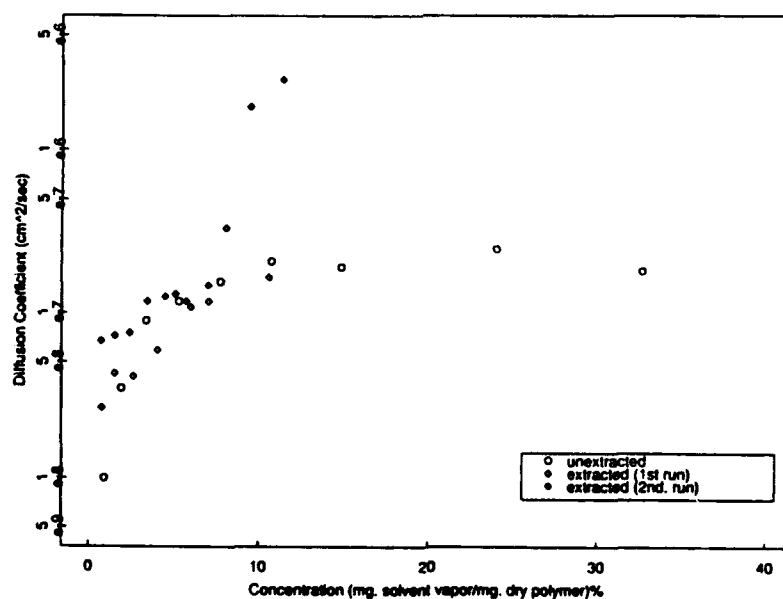


Figure 12. Investigation of the influence of plasticizer on the diffusion coefficient.

The diffusion coefficient obtained in the analysis of the unextracted and the extracted Neoprene samples were expressed in terms of the self-diffusion coefficient or solvent mobility D_1 . The mean diffusion constant obtained in the sorption interval was first converted to the mutual diffusion coefficient $D_{1,2}$ using the relation:

$$D_{1,2} = \frac{D}{\Phi_2^2} \quad (3)$$

where Φ_2 is the volume fraction of the polymer at the adjusted concentration (see Equation 2). Then, the self-diffusion coefficient or solvent mobility was obtained using the relation:

$$D_1 = \left(\frac{1}{\Phi_2} \right) \left(\frac{d \ln \Phi_1}{d \ln a_1} \right)_{T,P} D_{1,2} \quad (4)$$

where the thermodynamic factor, $(d \ln \Phi_1 / d \ln a_1)_{T,P}$ was obtained from the slope of the sorption isotherm. The results for the solvent mobility and the mutual diffusion coefficient plotted in Figure 13 showed that the diffusion coefficient rapidly increased with concentration at low concentration then started to more or less level off at higher concentration. Interestingly, these curves show, within experimental error, that the mutual diffusion for the extracted Neoprene was about the same as the mutual diffusion for the unextracted sample. The self-diffusion coefficient (solvent mobility) for the extracted sample was not as clear. If the last three data points for the self-diffusion coefficient of the extracted sample were ignored, then it would be possible to say that the self-diffusion coefficient for the extracted and the unextracted were similar.

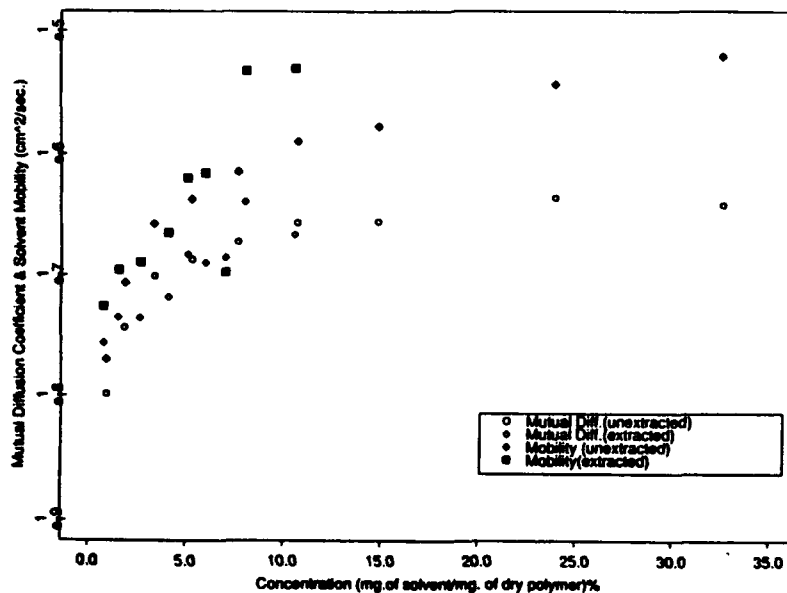


Figure 13. Investigation of the influence of plasticizer on the mutual and self-diffusion coefficient.

Sorption Isotherms

The sorption isotherm which represents the sorbed concentration as weight percent (mg of solvent vapor/mg of dry polymer) versus activity for the unextracted and the extracted sample are shown in Figure 14. The sorption isotherms for the unextracted Neoprene behaved as that of a high penetrant uptake in a rubbery polymer. It displayed an initial linear increase then a sharp bend as activity approached unity. The sorption isotherms for the extracted, on the other hand, increased linearly with concentration. Comparison of the isotherm for the extracted and the unextracted sample demonstrated that at a given activity, the increase in concentration was higher for the unextracted than for the extracted sample indicating that the presence of plasticizer had reduced the activity of vapor mix. Therefore, in order to reach equilibrium the polymer swelled more where the plasticizer was present. To plot the data (sorption curves and sorption isotherms, etc.) for the second run of the extracted sample, the difference in weight (0.3 mg) which resulted from the fact that the sample did not completely desorb at the end of the desorption run was added to the results of the second sorption run. All the calculations were done with respect to the dry polymer. Interestingly, although the second sorption run for the extracted sample did not overlap with the first, their sorption isotherms more or less did.

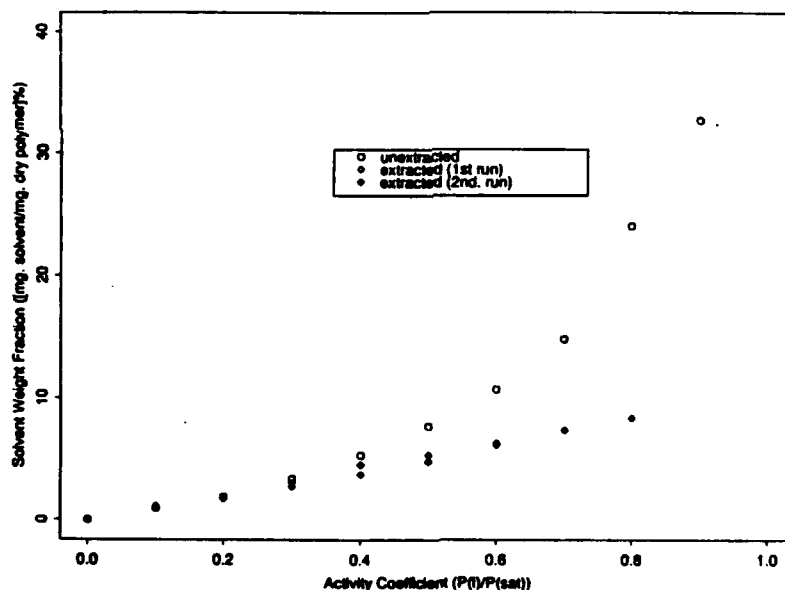


Figure 14. Investigation of the influence of plasticizer on the sorption isotherm.

An attempt was made to fit the Flory-Rehner equation:

$$\ln(a) = \ln(1 - \Phi_2) + \Phi_2 + \chi \Phi_2^2 + \frac{\rho V_1}{M_c} \left[1 - 2 \frac{M_c}{M} \right] \left[\Phi_2^{1/3} - \frac{\Phi_2}{2} \right] \quad (5)$$

where a is the solvent activity, Φ_2 is the polymer volume fraction, χ is the solvent-polymer interaction parameter, ρ is the polymer density, V_1 is the solvent molar volume, M_c is the molecular weight between crosslinks, and M is the molecular weight of the polymer. For convenience in modeling, $\rho V_1/M_c[1-2M_c/M]$ in the above equation was set equal to K . Then, using Φ_2 obtained from the immersion data at activity of one and $K = 0.002$, a value of $\chi = 0.8$ was determined for the unextracted Neoprene using Equation 5. The Flory-Rhener equation fit well with the experimental sorption isotherm for the unextracted Neoprene (see Figure 15).

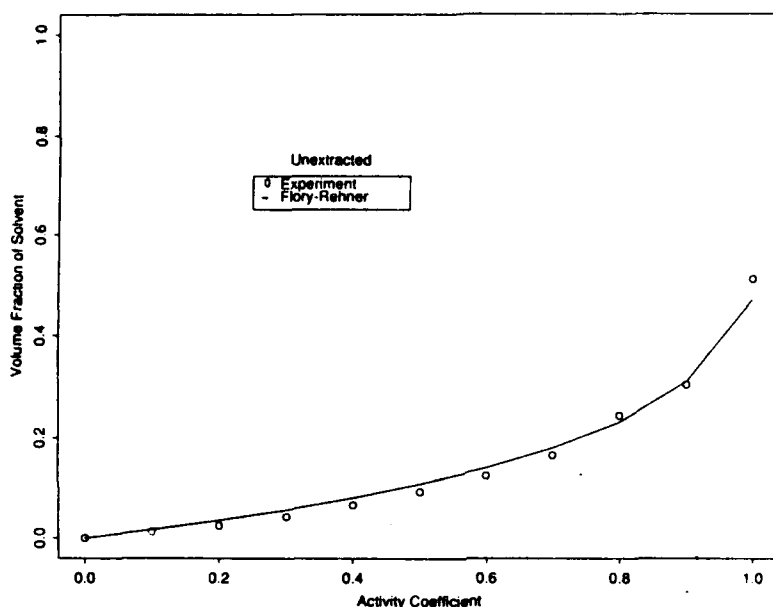


Figure 15. Comparison of Flory-Rhener isotherm with the experimental data for the unextracted sample.

Conclusion

The vapor sorption experiments for 1,4-dioxane in Neoprene had shown that the isotherm for the unextracted sample behaved like that of a high penetrant uptake in a rubbery polymer. It exponentially increased as activity increased. Also, it clearly shows that at a given activity the increases in concentration were higher for the unextracted than for the extracted Neoprene. On the other hand, observation of the diffusion coefficients demonstrate that within the experimental error there is no significant difference between the diffusion coefficient for the unextracted and the extracted Neoprene. This conflicts with the expectation that the plasticizer would increase the diffusion coefficient by at least an order of magnitude as observed for the initial dependence on the solvent concentration. Therefore, for any given vapor pressure, the permeation rate of the extracted sample which depends on the product of D and C will be lower than that for the unextracted sample.

In the mathematical model for the droplet permeation (1), the assumptions were: the diffusion coefficient was independent of concentration; at the emerging surface of the membrane the concentration was zero or close to zero depending on the gas stream mass transfer resistance; and at the upstream surface the concentration was equal to the equilibrium concentration. This means that at the emerging surface the diffusion coefficient will be closer to D_0 than to D which corresponds to the diffusion coefficient at the equilibrium concentration. This study clearly showed that D_0 is about three orders of magnitude lower than the diffusion coefficient at the upper surface of the membrane which itself is equivalent to the diffusion coefficient at an activity of one. Based on the observations in this study, it can be seen that the dependence of the diffusion coefficient on concentration must be taken into consideration and further experimental study for those chemical agents is needed.

Acknowledgment

The author wishes to acknowledge Dr. Nathan Schneider from Geo-Centers, Inc., 7 Wells Avenue, Newton, MA for his advice and comments.

References

1. SEVERE, G., and MELDON, J. *Numerical Simulation of Permeation from Deposited Droplets: Model Expansion*. U.S. Army Materials Technology Laboratory, MTL-TR 92-23, April 1992.
2. SEGERS, D. P., and SPAFFORD, R. B. *Immersion and Permeation Testing of Chemical Agent Polymers*. Southern Research Institute, U.S. Army Materials Technology Laboratory, MTL-TR 87-60, December 1987.
3. CRANK, J., and PARK, G. S. *Diffusion in Polymers*. Academic Press, London, England and New York, NY, 1968.
4. KHINNAVAR, R. S., and AMNABHAVI, T. M. *Resistance of Barrier Elastomers to Hazardous Organic Liquids*. J. Applied Polymer Science, v. 45, 1992, p. 1107-1125.
5. CRANK, J. *The Mathematics of Diffusion*. Oxford Press, 2nd ed., London, England, 1975.
6. DUBA, J. L., NI, Y. C., and VRENTAS, J. S. J. Polym. Sci., Polym. Phys. Ed, v. 15, 1977, p. 2039.
7. WAKSMAN, L. S., SCHNEIDER, N. S., and SUNG, N. H. *Barrier Polymers and Structures*. W. J. Koros, ed., AS Symposium, American Chemical Society, Series No. 423, Washington, DC, 1990.
8. SCHNEIDER, N. S., MOSEMAN, J. A., and SUNG, N. *Toluene Diffusion in Butyl Rubber*. In press.

DISTRIBUTION LIST

No. of Copies	To
	Commander, U.S. Army Chemical and Biological Defense Agency, Aberdeen Proving Ground, MD 21010-5423
1	ATTN: AMSCB-CIH, J. K. Smart
2	AMSCB-CII, Library
1	AMSCB-CIM, S. Lawhorne
1	AMSCB-EO
	Director, U.S. Army Edgewood Research, Development and Engineering Center, Aberdeen Proving Ground, MD 21010-5423
1	ATTN: SCBRD-ASI
1	SCBRD-EN
1	SCBRD-ENE, Dr. P. Patel
1	SCBRD-RT, Dr. J. Baker
1	SCBRD-RT, A. K. Stuempfle
1	SCBRD-RT, Dr. J. R. Ward
1	SCBRD-RTE, J. Thompson
1	SCBRD-RTE, R. Steger
1	SCBRD-RTL, L. Miller
1	SCBRD-RTL, Dr. H. Salem
1	SCBRD-RTM, C. Crawford
1	SCBRD-RT, Tech Rel Ofc
1	SCBRD-RTC, W. Shuely
1	SCBRD-RTC, B. Ince
	Huntsville Division, Corps of Engineers, P.O. Box 1600, Huntsville, AL 35807-4301
1	ATTN: CEHND-PM-MD, R. A. Belew
	Commandant, U.S. Army Ordnance Missile and Munitions Center and School, Redstone Arsenal, AL 35897-6903
1	ATTN: ATSK-TMT, CPT Glover
	Commander, U.S. Army Missile Command, Redstone Scientific Information Center, Redstone Arsenal, AL 35898-5241
2	ATTN: AMSMI-RD-CS-R/Documents
	Commander, Anniston Army Depot, Anniston, AL 36201-5009
1	ATTN: SDSAN-CS
	Commandant, U.S. Army Chemical School, Fort McClellan, AL 36205-5020
1	ATTN: ATZN-CM-CC
1	ATTN: ATZN-CM-CS, Deputy MLSD
1	ATTN: ATZN-CM-CT, C. E. Jennings
1	ATTN: ATZN-CM-EE, SFC Matheny
1	ATTN: ATZN-CM-FISC
	Commander, U.S. Army Aviation Center, Fort Rucker, AL 36362-5000
1	ATTN: ATZQ-TDC-CS, NBC/CSS
	Commander, Pine Bluff Arsenal, Pine Bluff, AR 71602-9500
1	ATTN: SMCPB-MM, C. K. Dunem

No. of Copies	To
1	HQDA, DAMO-SWC, Pentagon, Room 3C549, Washington, DC 20310-0430
1	HQDA, DAMI-FIT-S&T, Washington, DC 20310-1087
1	Director, Defense Intelligence Agency, Washington, DC 20340-6053 ATTN: DTI-5C, Dr. Eck
1	Commander, Naval Sea Systems Command, Washington, DC 20362-5160 ATTN: Code 05R24, S. Enatsky
1	HQ, AFCESA/DXD, 139 Barnes Drive, Tyndall AFB, FL 32403-5319
1	28th TESTS/TCO, 203 W. D Avenue, Suite 400, Eglin AFB, FL 32542-6867
1	Commander, U.S. Army Armament, Munitions and Chemical Command, Rock Island, IL 61299-6000 ATTN: AMSMC-ASN
1	AMSMC-EQ
1	AMSMC-SFS
1	Commander, U.S. Army Chemical and Biological Defense Agency, Rock Island, IL 61299-7410 ATTN: ACBRD-ES (R)
1	Commander, U.S. Army Armor Center, Fort Knox, KY 40121-5215 ATTN: ATZK-COS
1	Commander, U.S. Army Natick Research, Development and Engineering Center, Kansas Street, Natick, MA 01760-5015 ATTN: SATNC-AA, D. Malabarba
1	Commander, U.S. Army Natick Research, Development and Engineering Center, Kansas Street, Natick, MA 01760-5018 ATTN: SATNC-WTS
1	Commander, U.S. Army Natick Research, Development and Engineering Center, Kansas Street, Natick, MA 01760-5019 ATTN: SATNC-ICP, R. Granchelli
1	SATNC-ITP, Dr. W. Wilusz
1	Commander, U.S. Army Natick Research, Development and Engineering Center, Kansas Street, Natick, MA 01760-5020 ATTN: SATNC-YBH, Dr. C. K. Bensei
1	SATNC-YM, Dr. D. L. Kaplan
1	SATNC-YSP, Dr. D. H. Robertson
1	Commander, U.S. Army Natick Research, Development and Engineering Center, Kansas Street, Natick, MA 01760-5040 ATTN: SATNC-MIL, Technical Library

No. of Copies	To
1	Commanding Officer, Naval Explosive Ordnance Disposal Technology Center, Indian Head, MD 20640-5040 ATTN: ATTN: B1
1	Commander, Detachment S, USAFIA, Fort Meade, MD 20755-5985 ATTN: IAFIA-S
1	Director, U.S. Army Survivability Management Office, 2800 Powder Mill Road, Adelphi, MD 20783-1145 ATTN: SLCSM-AA, D. D. Manyak
1	Director, U.S. Army Concepts Analysis Agency, 8120 Woodmont Avenue, Bethesda, MD 20814-2797 ATTN: CSCA-SPN
1	Chief, U.S. Army Edgewood Research, Development and Engineering Center Field Element, Aberdeen Proving Ground, MD 21005-5001 ATTN: AMSRL-HR-MM, D. Harrah
1	Commander, U.S. Army Test and Evaluation Command, Aberdeen Proving Ground, MD 21005-5055 ATTN: AMSTE-TA-S
1	Director, U.S. Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD 21005-5071 ATTN: AMXS-Y-CR, C. Horley AMXS-Y-MP, H. Cohen
1	Commander, U.S. Army Environmental Hygiene Agency, Aberdeen Proving Ground, MD 21010-5422 ATTN: HSHB-MO-A HSHB-MO-T
1	Director, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD 21010-5423 ATTN: AMSRL-SL-N, M. Miller AMSRL-SL-NO, A. Van de Wal
1	Commander, U.S. Army Technical Escort Unit, Aberdeen Proving Ground, MD 21010-5423 ATTN: SMCTE-OP
1	Commander, U.S. Army Medical Research Institute of Chemical Defense, Aberdeen Proving Ground, MD 21010-5425 ATTN: SGRD-UV-AI-W
1	Director, Armed Forces Medical Intelligence Center, Bldg. 1607, Fort Detrick, Frederick, MD 21702-5004 ATTN: AFMIC-IS
1	Commander, U.S. Army Aviation System Command, 4300 Goodfellow Boulevard, St. Louis, MO 63120-1798 ATTN: AMSAV-NS, R. Breitenbach

No. of Copies	To
1	Director, U.S. Army Research Office, P.O. Box 12211, Research Triangle Park, NC 27709-2211 ATTN: AMXRO-CB, Dr. R. Ghiradelli
1	Commander, U.S. Army Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755-1290 ATTN: CECRL-RC, D. Leggett
1	CECRL-EA, L. Parker
1	Commander, U.S. Army Chemical Activity Pacific, APO AP 96558-0008 ATTN: APCA-XO
1	FASTC/TATH, Wright-Patterson AFB, OH 45433-6508
1	Commander, U.S. Army Biomedical Research and Development Research Laboratory, Bldg 79, Area B, Wright-Patterson AFB, OH 45433-6573 ATTN: OL-AL/OET
1	Commander, U.S. Army Depot System Command, Chambersburg, PA 17201-4170 ATTN: AMSDS-QA-V, R. Harris
1	AMSDS-IN-S, R. Garver
1	Commanding Officer, Naval Air Warfare Center, Aircraft Division Warminster, P.O. Box 5152, Warminster, PA 18974-0591 ATTN: Code 60241, D. J. Herbert
1	Commander, 2d Armored Division, Chemical Division, Fort Hood, TX 76544-5200 ATTN: UIC WH7BAA
1	Commandant, U.S. Army Medical Department Center and School, Fort Sam, Houston, TX 78234-6100 ATTN: HSMC-FCS, Dr. Mosebar
1	HSHA-MP
1	Commander, U.S. Army Dugway Proving Ground, Dugway, UT 84022-5000 ATTN: STEDP-JOD-I
1	Commander, U.S. Army Nuclear and Chemical Agency, 7500 Backlick Road, Bldg 5073, Springfield, VA 22150-3198 ATTN: MONA-CM
2	Commander, Defense Technical Information Center, Cameron Station, Bldg 5, Alexandria, VA 22304-6145 ATTN: DTIC-FDAC
1	Commander, U.S. Army Materiel Command, 5001 Eisenhower Avenue, Alexandria, VA 22333-0001 ATTN: AMCSCI

No. of Copies	To
1	Commander, Naval Surface Warfare Center, Dahlgren, VA 22448-5000
1	ATTN: Code B53, M. A. Pompeii
1	Code H305, Dr. J. L. Brumfield
1	Commander, U.S. Army Foreign Science and Technology Center, 220 7th Street, N.E., Charlottesville, VA 22901-5000
1	ATTN: IAFSTC-RIB
1	Commander, U.S. Army Training and Doctrine Command, Fort Monroe, VA 23651-5000
1	ATTN: ARCD-GB
1	HQ, ACC/DRWC, 204 Dodd Boulevard, Suite 226, Langley AFB, VA 23665-5575
1	Director, U.S. Army Research Laboratory, 2800 Powder Mill Road, Adelphi, MD 20783-1197
1	ATTN: AMSRL-OP-SD-TP, Technical Publishing Branch
1	AMSRL-OP-SD-TM, Records Management Administrator
1	Commander, U.S. Army Tank-Automotive Command, Warren, MI 48090
1	ATTN: AMSTA-JSS, R. Case
1	AMSTA-FTT, A. Pacis
1	U.S. Environmental Protection Agency, Woodbridge Avenue, MS-104, Edison, NJ 08837-3679
1	ATTN: Exposure Reduction Technology Section, M. Gruenfeld
2	Director, U.S. Army Research Laboratory, Watertown, MA 02172-0001
5	ATTN: AMSRL-OP-WT-IS Technical Library Author